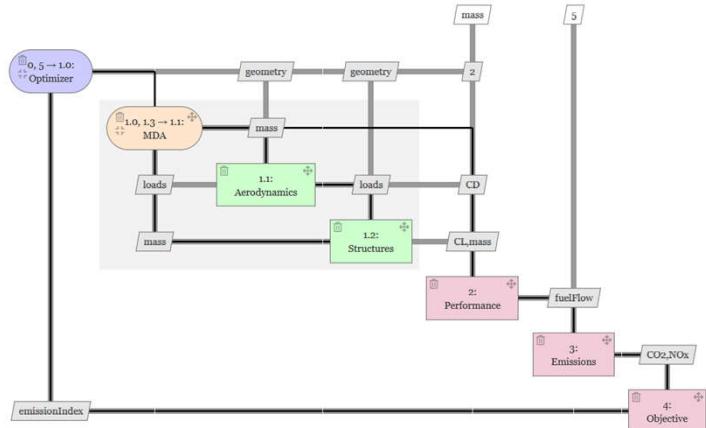


MDAx Step-by-Step Example



Knowledge for Tomorrow

MDAx: MDO Workflow Design x +

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Login to MDAx Server

Username Username

Password Password

Legal - impressum About MDAx Login

MDAx MDO Workflow Design Accelerator DLR

Use your username and password to log in.

To add single tools using its input/output (I/O) definition, click on the dashed block in the center or the *Tool* button in the toolbar.

MDAx: MDO Workflow Design x +

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Simple Emissions

Add Disciplinary Analysis Tool

Tool Name required

Function name

Notes

Tool Version

Tool version

Upload the XML files specifying the input and output of the disciplinary analysis tool.
The input file should contain "input" in its file name, the output file should contain "output".
It is possible to only upload one of the two, or not upload any at all.

I/O Definition

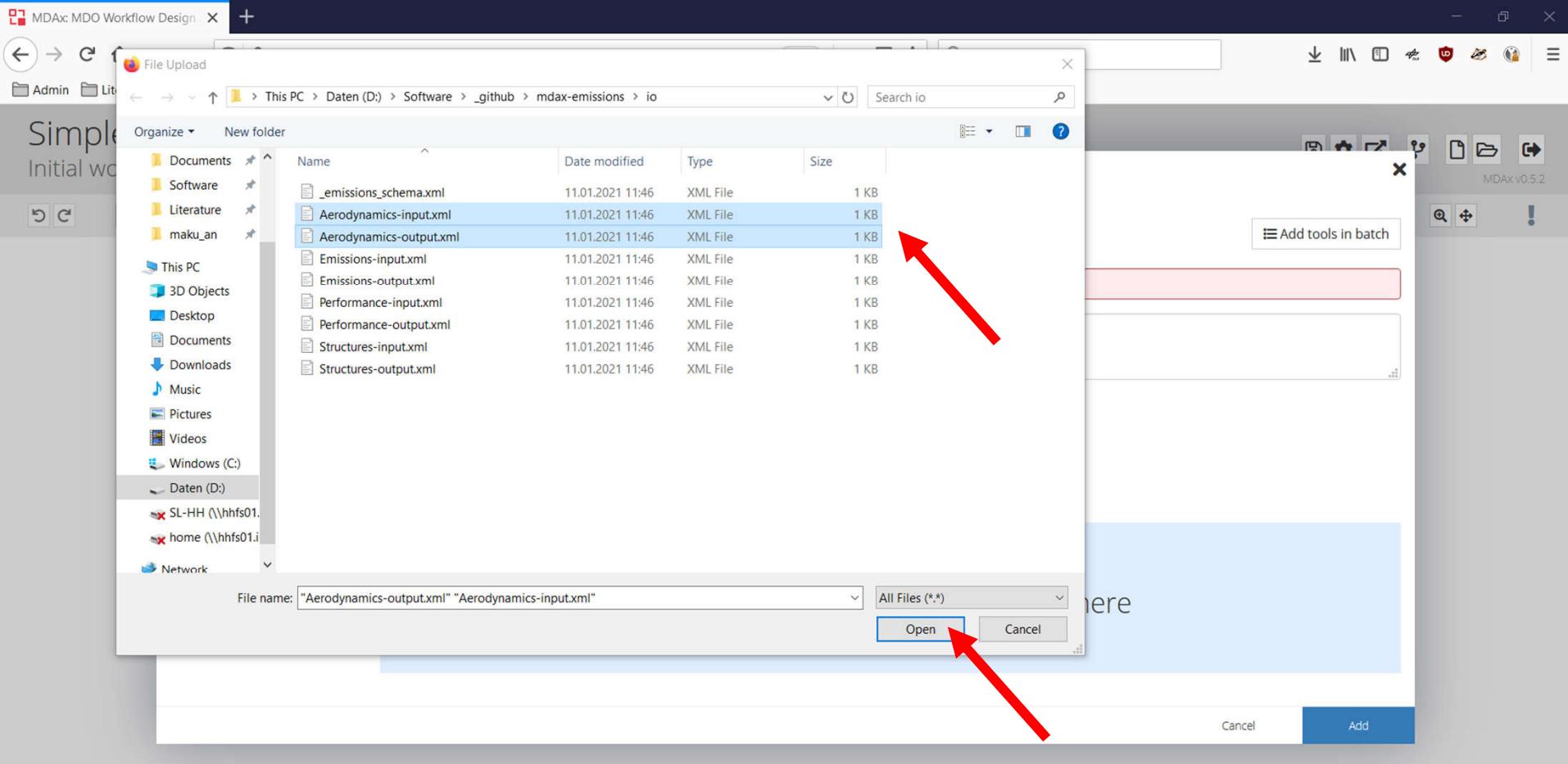
Upload I/O XML files: click or drag here

Cancel Add

The screenshot shows a web-based application window titled 'MDAx: MDO Workflow Design'. The main title is 'Simple Emissions' with a subtitle 'Initial workflow'. A modal dialog box is open with the heading 'Add Disciplinary Analysis Tool'. Inside the dialog, there are fields for 'Tool Name' (labeled 'required') and 'Notes', and another for 'Tool Version'. Below these is a note about uploading XML files for I/O definition. At the bottom is a large blue area labeled 'Upload I/O XML files: click or drag here'. Two red arrows are overlaid on the image: one pointing to the 'Tool Name required' label and another pointing to the 'Upload I/O XML files' area. The bottom right of the dialog has 'Cancel' and 'Add' buttons. The overall interface is clean with a light gray background and white text for most elements.

Set the name for your tool and click on the blue area to select the I/O definition. If you prefer MDAx to automatically detect the tool name from the definition files, leave the name field empty.





Select one input and one output definition file, and click **Open**.

Simple Emissions

Initial workflow

Add Disciplinary Analysis Tool

Tool Name Aerodynamics

Notes

Tool Version Tool version

Upload the XML files specifying the input and output of the disciplinary analysis tool.
The input file should contain "Input" in its file name, the output file should contain "output".
It is possible to only upload one of the two, or not upload any at all.

I/O Definition

Selected file: **Aerodynamics-input.xml** 

Selected file: **Aerodynamics-output.xml** 

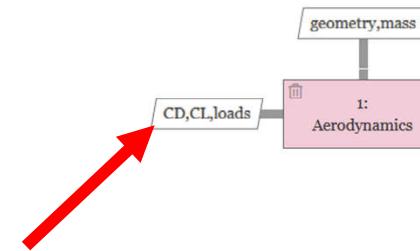
 Cancel Add

I/O Definition Selected file: Aerodynamics-input.xml []
Selected file: Aerodynamics-output.xml []

Car



The input and output files are imported and listed in the menu. Click **Add** to proceed.



To inspect the inputs and outputs of your imported tool, click on the *variable blocks*, or click on the tool block...

MDAx: MDO Workflow Design x +

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Simple Emissions

Edit Disciplinary Analysis Tool

single

Opt

View / edit input ➔

1: Aerodynamics

View / edit output ➔

Tool Name: Aerodynamics

Notes:

Tool Version: Tool version

Upload the XML files specifying the input and output of the disciplinary analysis tool.
The input file should contain "input" in its file name, the output file should contain "output".
It is possible to only upload one of the two, or not upload any at all.

I/O Definition

Upload I/O XML files: click or drag here

Cancel Update



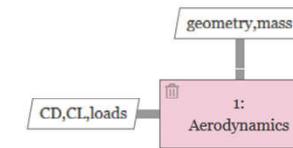
MDAx MDO Workflow Design Administrator DLR

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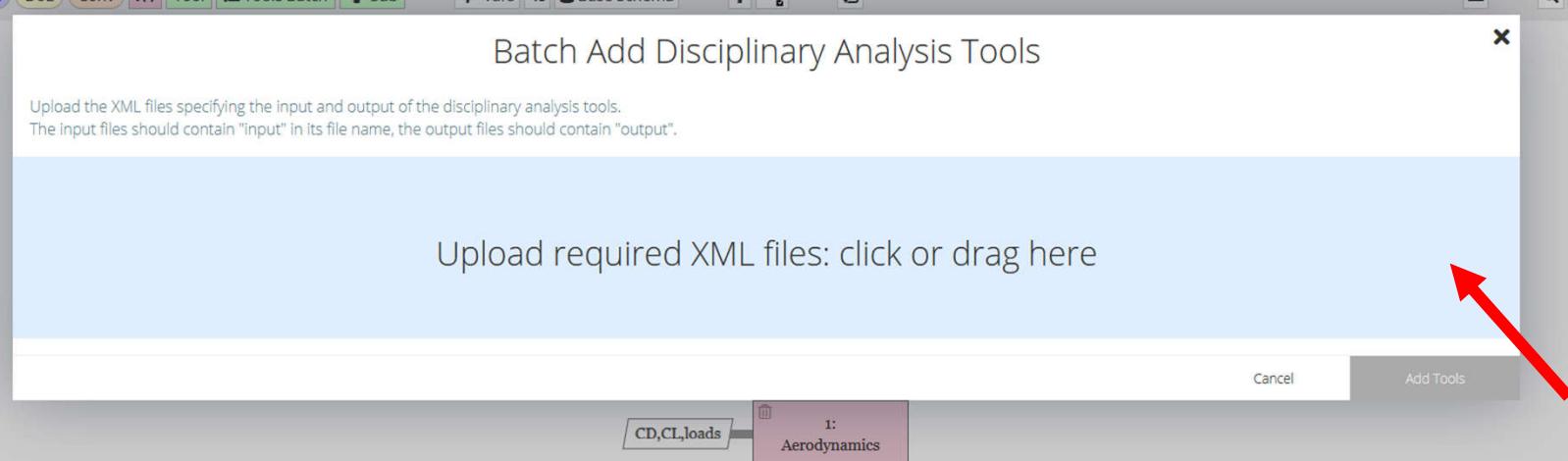
...and in the tool window, click the *input* or *output* button.

This opens the variable tree that shows the inputs or outputs of that tool.

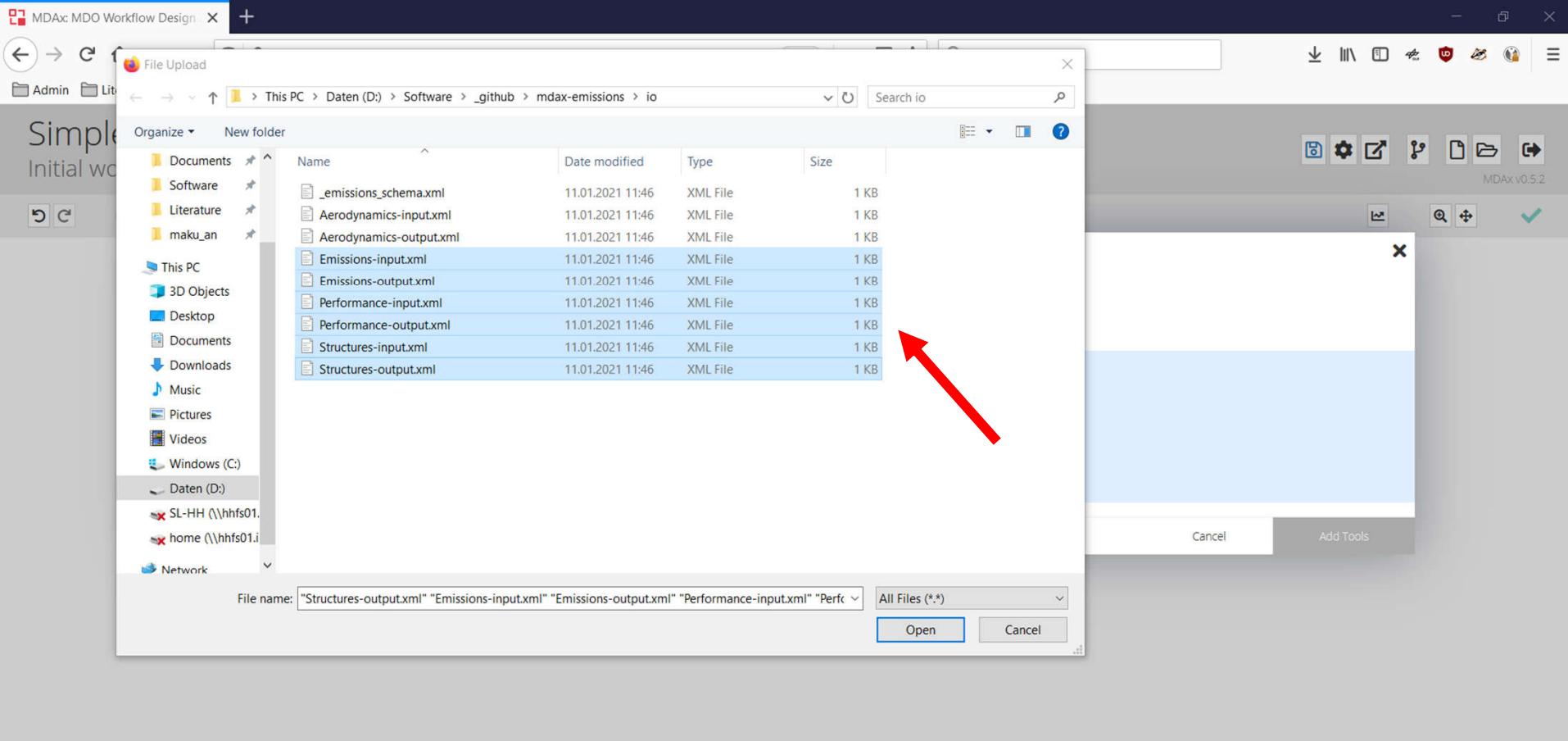




To add multiple tools at once, click *Tool Batch*



As with the single tool, click the blue area...



...and select the input and output definitions for the tools you would like to add. Here, you can select multiple files for import...

MDAx: MDO Workflow Design x +

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Simple E Initial workflow

Batch Add Disciplinary Analysis Tools

Upload the XML files specifying the input and output of the disciplinary analysis tools.
The input files should contain "input" in its file name, the output files should contain "output".

Selected file: Emissions-input.xml
Selected file: Emissions-output.xml
Selected file: Performance-input.xml
Selected file: Performance-output.xml
Selected file: Structures-input.xml
Selected file: Structures-output.xml

Upload required XML files: click or drag here

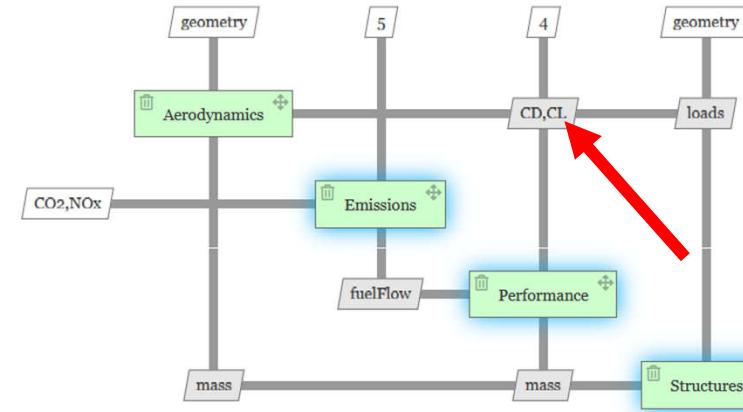
Use the table below to link the uploaded input/output files to tools to be created.
It is possible to create tools which only have either input or output.

Tool Name	Input File	Output File	Actions
Emissions	Emissions-input.xml	Emissions-output.xml	
Performance	Performance-input.xml	Performance-output.xml	
Structures	Structures-input.xml	Structures-output.xml	
Tool name			

Cancel Add Tools

MDAx MDO Workflow Design Accelerator DLR Legal - Impressum | About MDAx

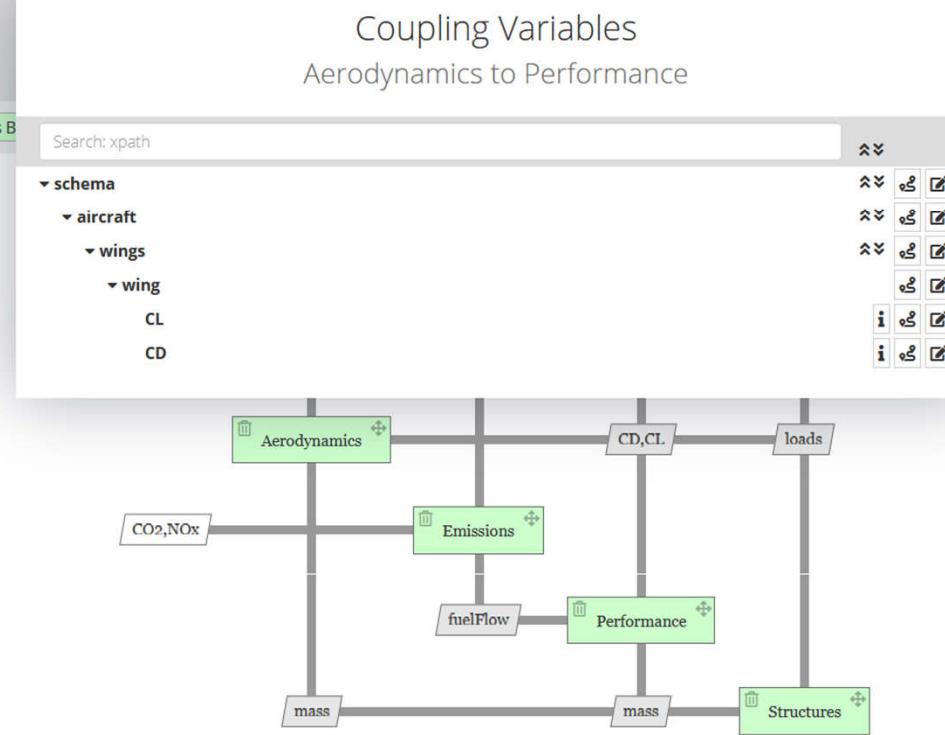
...and MDAx automatically recognizes the tool name based on the file naming convention *[tool name]-[input/output].[extension]*. Click *Add Tools* to add the selected tools to the canvas.



Now that multiple tools are added, you can inspect the connections between them by clicking on the parameter blocks.

Simple Emissions

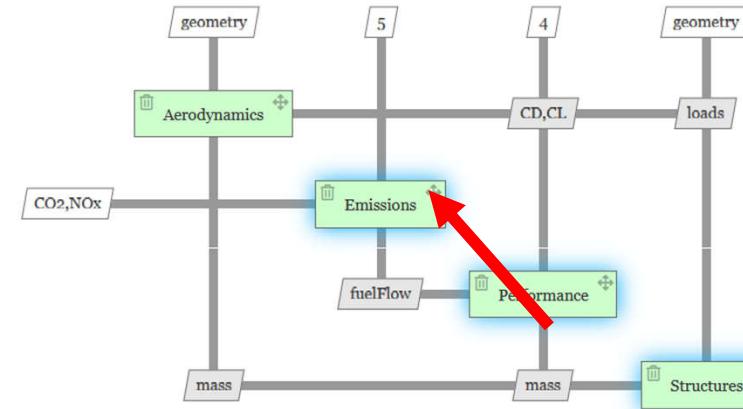
Initial workflow



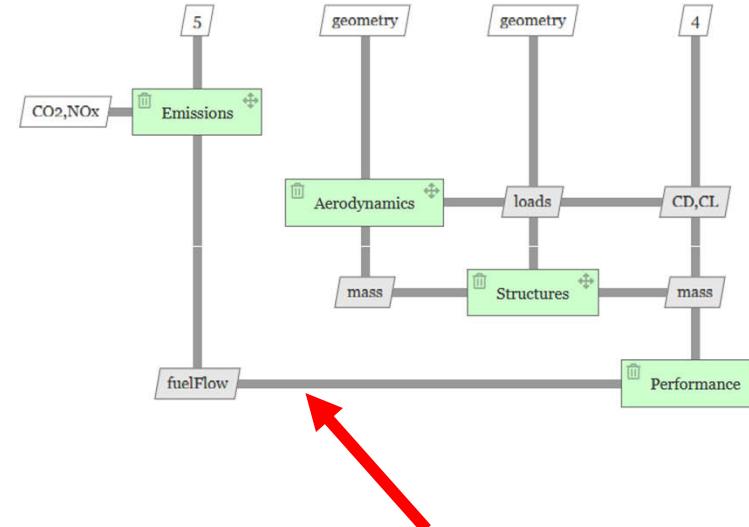
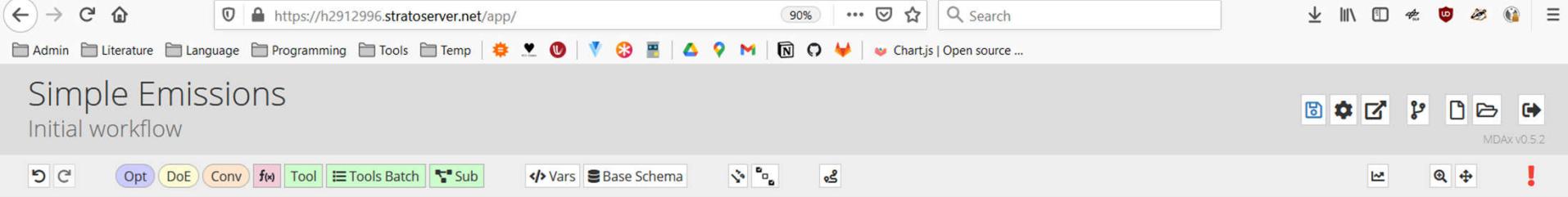
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The variable tree show which parameters are exchanged between the two tools.





You can drag and drop tool blocks using the icon in its top-right corner.

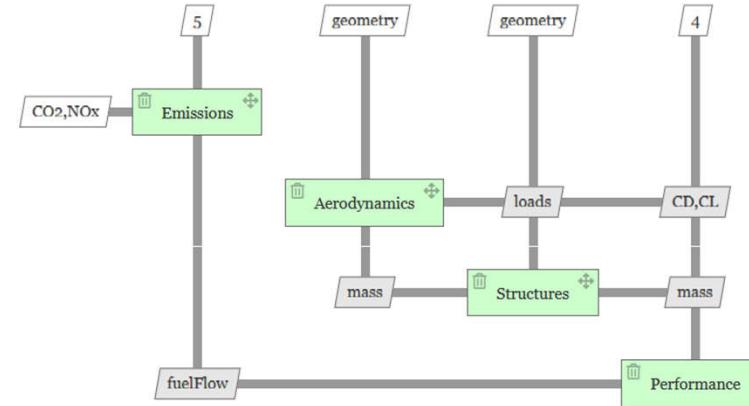


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Notice that forward and feedback connections change depending on the position of the tool in the workflow sequence. The sequence always goes from left to right.

Simple Emissions
Initial workflow

The screenshot shows the MDAx interface with a workflow titled "Simple Emissions". The workflow consists of the following nodes connected sequentially: "Emissions" (green), "Aerodynamics" (green), "Structures" (green), and "Performance" (green). Inputs include "CO2,NOx" and "fuelFlow" entering "Emissions", and "geometry" and "CD,CL" entering "Aerodynamics". Feedback connections exist from "Emissions" to "Aerodynamics" and from "Aerodynamics" to "Structures". Outputs from "Structures" and "Performance" are "loads" and "mass" respectively. A red arrow points to the "Auto Sort" button in the toolbar.



For complex workflows with many tools, MDAx offers a sorting algorithm that sorts the workflow sequence to minimize feedback connection. Click the *Auto Sort* button, ...

Simple Emissions

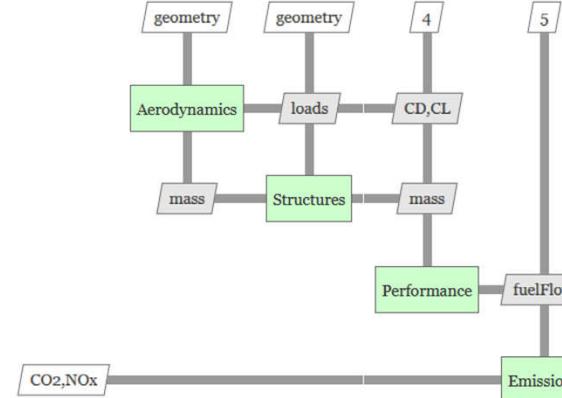
Initial workflow

Automated Function Sorting

Select Sorting Algorithm

- Current function order
 - Partitioning

Moves independent functions to the front, functions without output to the end, and groups independent loops. This algorithm works well for basic function positioning, but does not sort functions within a loop.



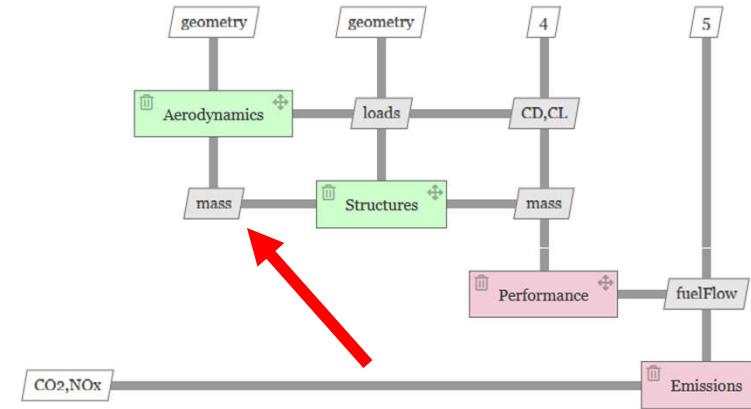
Cand

Apply Sortin

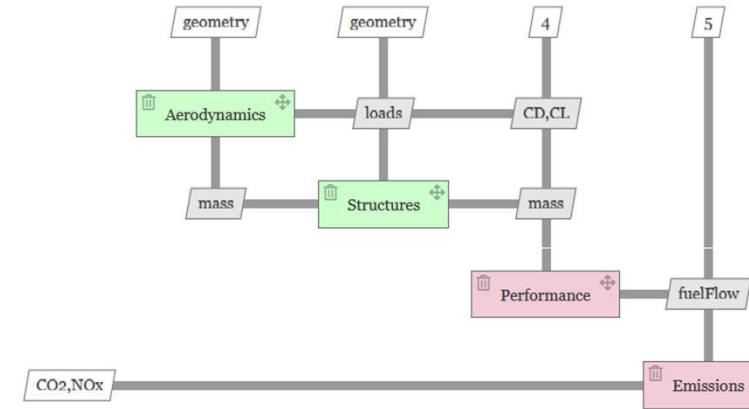


...select the the *Partitioning* option, and continue with *Apply Sorting*.

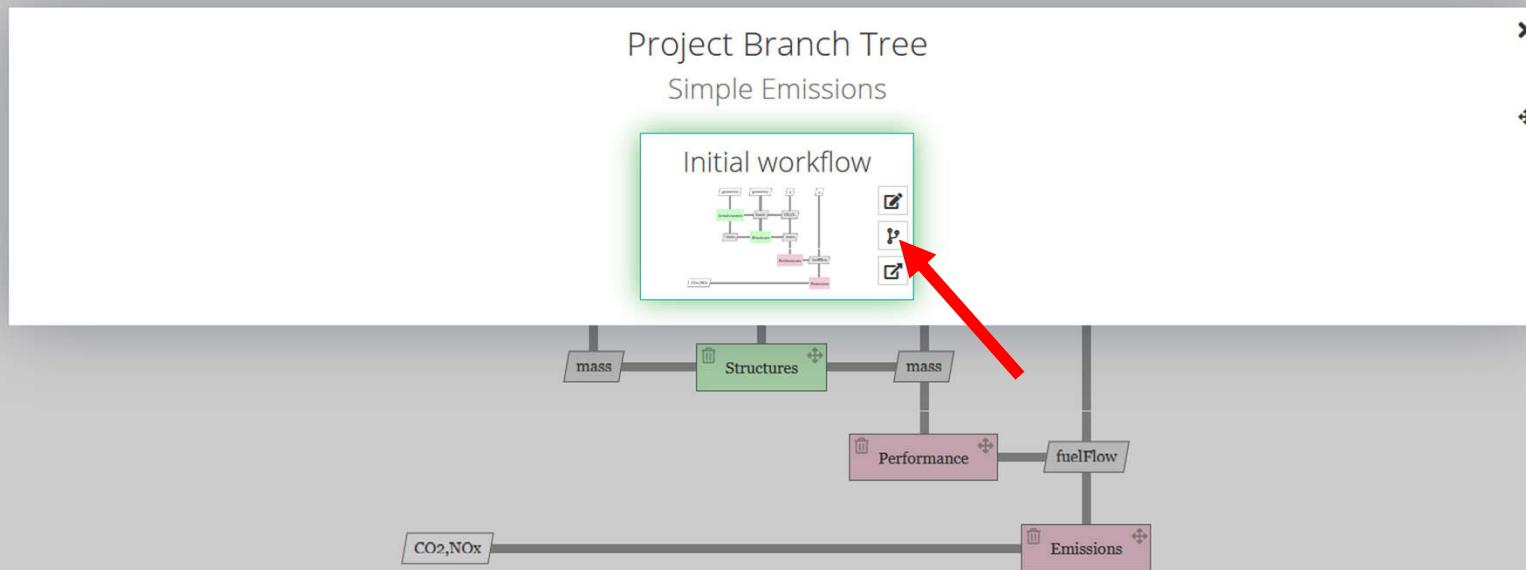




The resulting workflow will have a minimum amount of feedback connections.



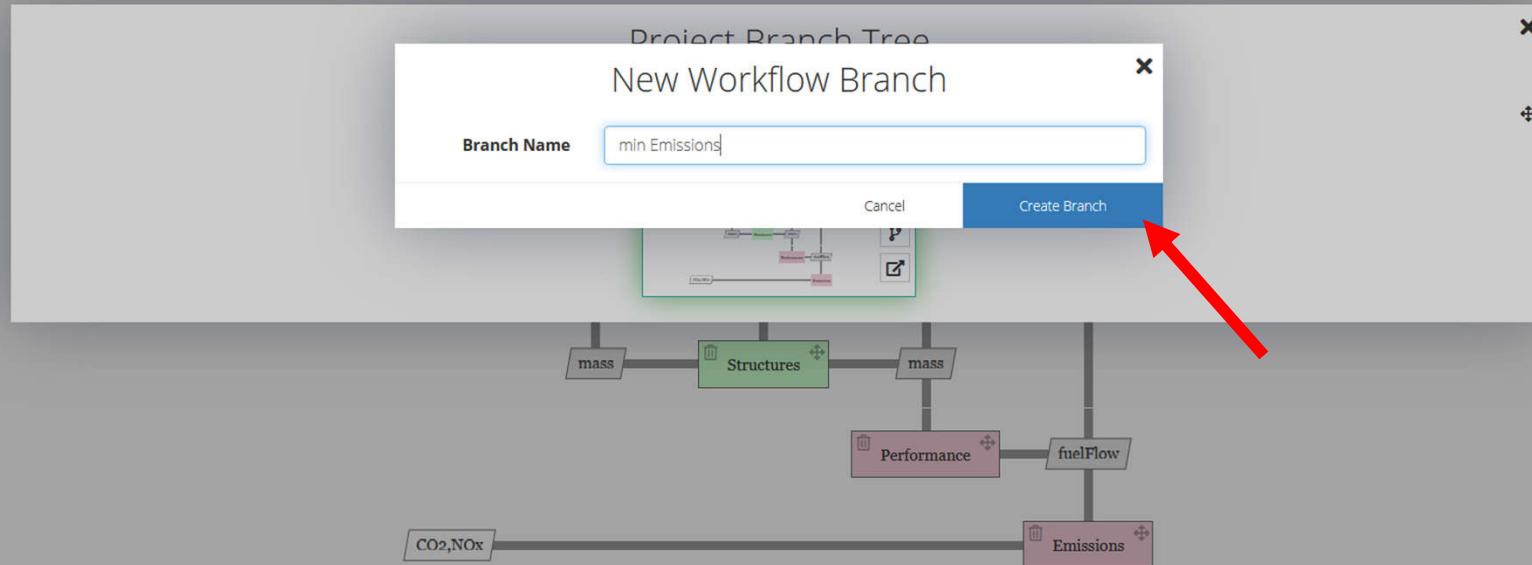
To help with workflow versioning, you can create workflow branches by clicking on the *Project Tree* button.



Here, click on the branching symbol of the workflow that you want to branch off from.

Simple Emissions

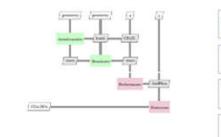
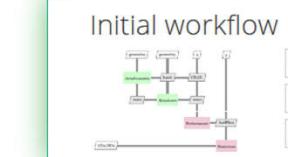
Initial workflow



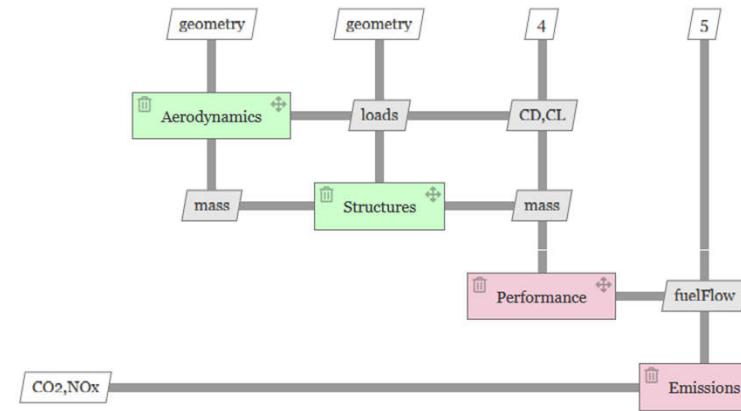
Define the new branch name and click *Create Branch*.

Simple Emissions

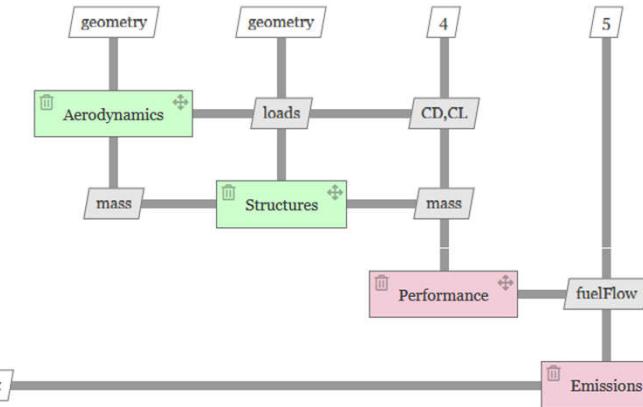
Initial workflow



This creates a derivative workflow that is based on the original workflow.



The current branch name is visible in the menu bar. We can perform changes to this workflow without affecting its parent workflow. Multiple branches can be created in parallel.



In this branch, we can demonstrate the removal of redundant tools. Redundant tools are tools that are not necessary for the computation of the parameters of interest. Click the *Remove unnecessary function* button.

MDAx: MDO Workflow Design x +

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Simple Emissions

min Emission

Automatically Remove Unnecessary Functions

Settings Preview

Output variables to keep

Variable	Actions
<input checked="" type="checkbox"/> Aerodynamics	+

Functions to keep

Function	Actions
Aerodynamics	+

Preview diagram:

```
graph LR; geometry1[geometry] --> Aerodynamics[Aerodynamics]; Aerodynamics --> loads[loads]; loads --> CDCL[CD, CL]; Aerodynamics --> mass1[mass]; mass1 --> Structures[Structures]; Structures --> mass2[mass]; CDCL --> Performance[Performance]; Performance --> fuelFlow[fuelFlow]; fuelFlow --> Emissions[Emissions]; CO2NOx[CO2, NOx] --> Emissions
```

Cancel Apply

A red arrow points to the checked checkbox in the "Variables" section of the "Output variables to keep" table.

Here we can specify variables and tools to keep. Click on the *Select variables* button...

...and select the variable(s) of interest

MDAx: MDO Workflow Design x +

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Simple Emissions

min Emission

Automatically Remove Unnecessary Functions

Settings

Output variables to keep

Variable	Actions
fuelFlow	

Functions to keep

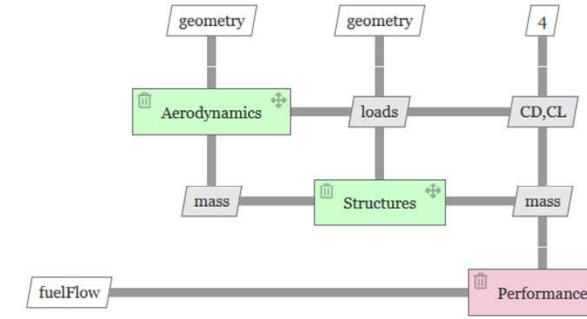
Function	Actions
Aerodynamics	

Preview

The preview shows a dependency graph with nodes: geometry (2), Aerodynamics, loads, CD, CL, mass (2), Structures, mass, Performance, fuelFlow, CO₂, NO_x, and Emissions. Aerodynamics and Structures are green boxes. Performance is a pink box. fuelFlow and Emissions are grey boxes. A red arrow points from the text "Click Apply to remove the highlighted tool(s)." to the "Apply" button at the bottom right of the dialog.

Cancel **Apply**

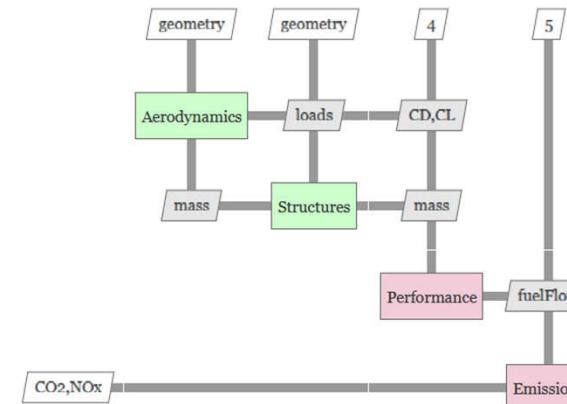
MDAx makes a dependency analysis and automatically determines which tools it can remove. Click *Apply* to remove the highlighted tool(s). The same functionality can be applied to function blocks.



The redundant tool is removed from the workflow. This is especially convenient in large, complex workflows. The user can import his entire tool repository and quickly determine which tools can be dropped.



Return to the original workflow



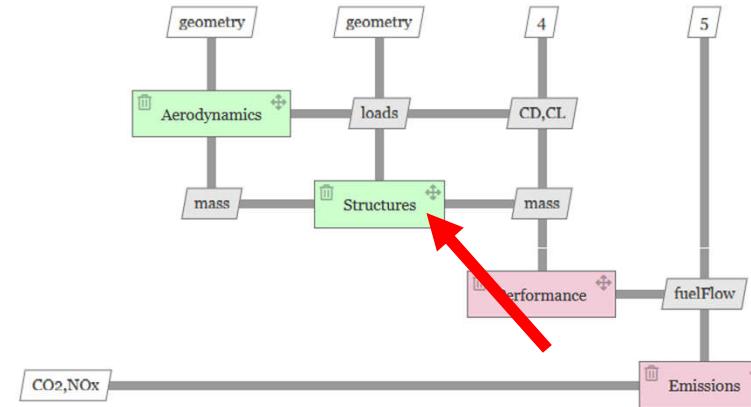
Here you can see that you can not edit it, because it has downstream branch dependency. Click *Start editing* ...



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To create a copy of the workflow in another branch. Select it to continue working.





In many workflows, variable collisions exist. Colliding variables are provided by more than one tool, and required by at least one other tool. The user has to clarify this ambiguity. To add a collision, click on the *Structures* block...

MDAx: MDO Workflow Design x +

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Simple Emissions

Edit Disciplinary Analysis Tool

Initial workflow

Tool Name: Structures

Notes:

Tool Version: Tool version

I/O Definition

Upload I/O XML files: click or drag here

View / edit input ➡ Structures View / edit output ➡

Cancel Update



MDAx v0.5.2

...and edit the tool output.



MDAx: MDO Workflow Design x +

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Simple Emissions
Initial workflow

Opt

Tool Name
Notes
Tool Version
I/O Definition

Output Variables

Structures

Search: xpath

schema
aircraft
wings
wing
mass
geometry
CL
loads
CD
fuselage
empennage
performance
fuel
mission

Cancel Update

A red arrow points to the link icon (), which is located in the toolbar of the variable editor window.

In the tree view, add an existing variable such as *CL* by clicking the *link* symbol.



MDAx: MDO Workflow Design

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Simple Emissions

Initial workflow

Opt

Tool Name: [redacted]

Notes: [redacted]

Tool Version: [redacted]

I/O Definition:

Output Variables

Structures

Search: xpath

schema

aircraft

wings

wing

mass

geometry

CL

loads

CD

fuselage

empennage

performance

fuel

mission

Cancel Update

Added CL to Structures output

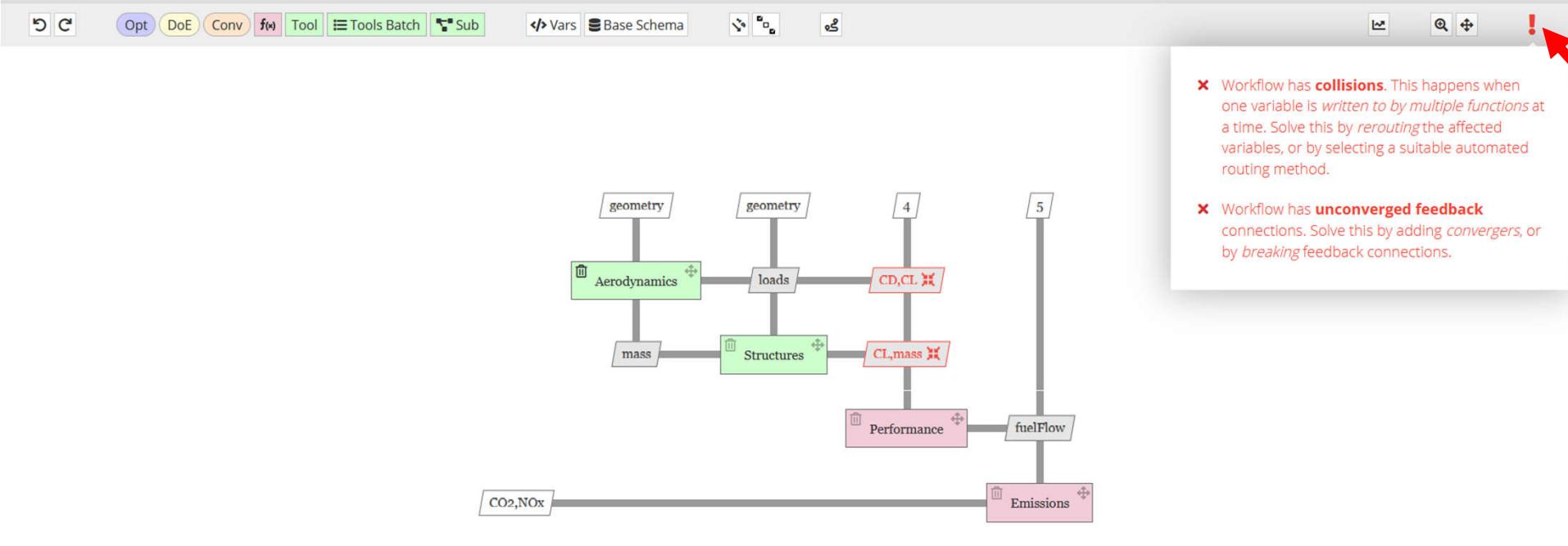
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This adds the CL parameters to the tool outputs, marked red to indicate that a variable collision exists on this parameter.

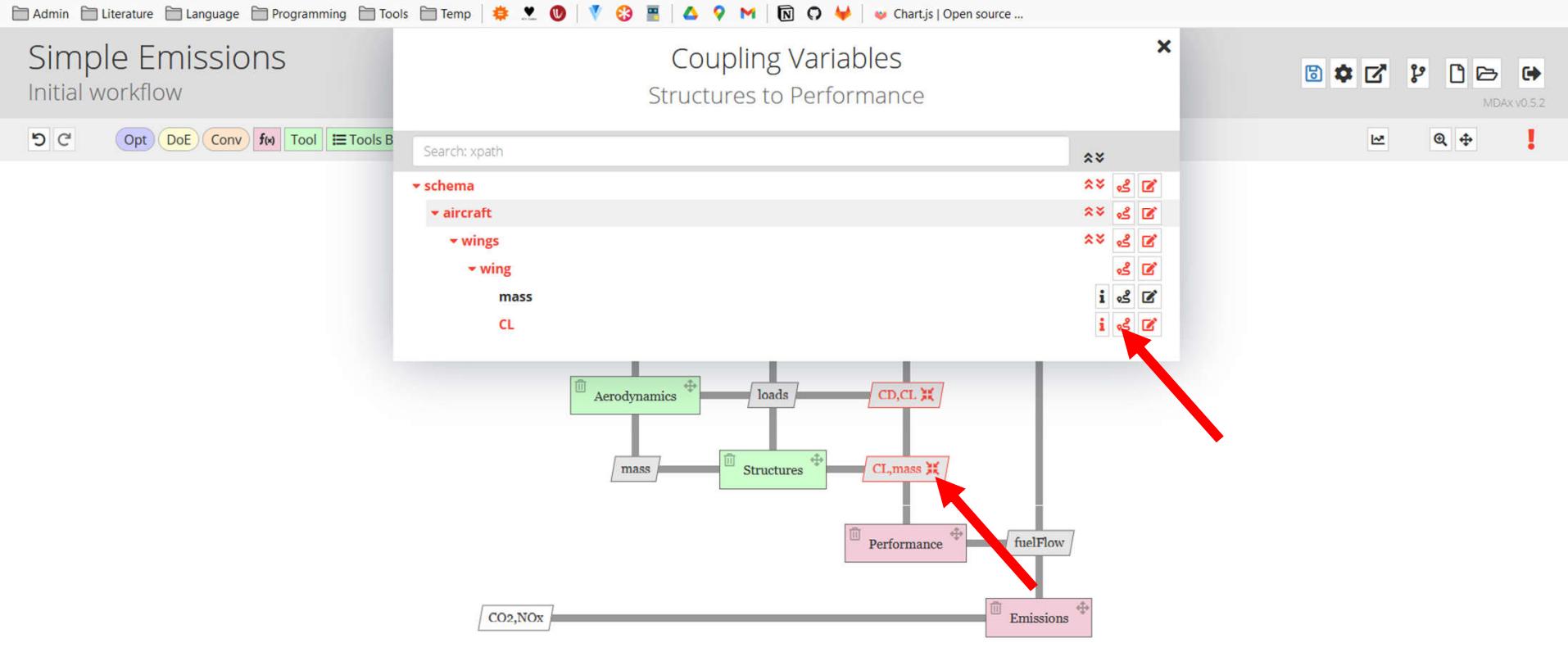


Simple Emissions

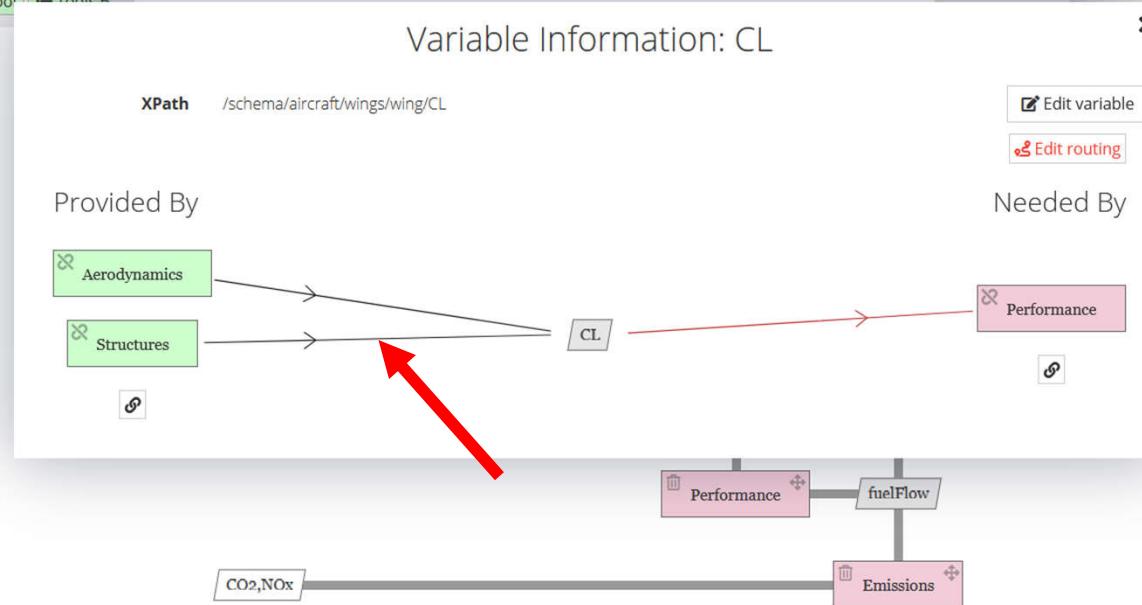
Initial workflow



MDAx now indicates that there are issues with collisions.



Looking at the tool connections, it is clear that *Aerodynamics* and *Structures* both provide *CL*, while *Performance* requires it. To manually resolve this ambiguity, click on the *Edit routing* button in the variable tree.



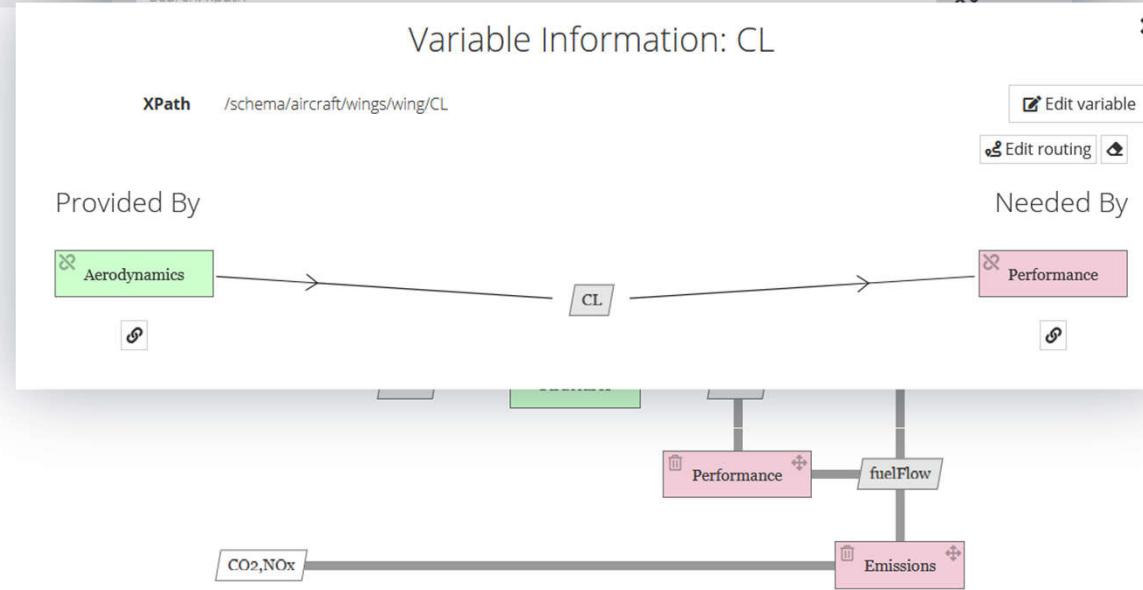
By clicking on the connection, you can manually remove it.

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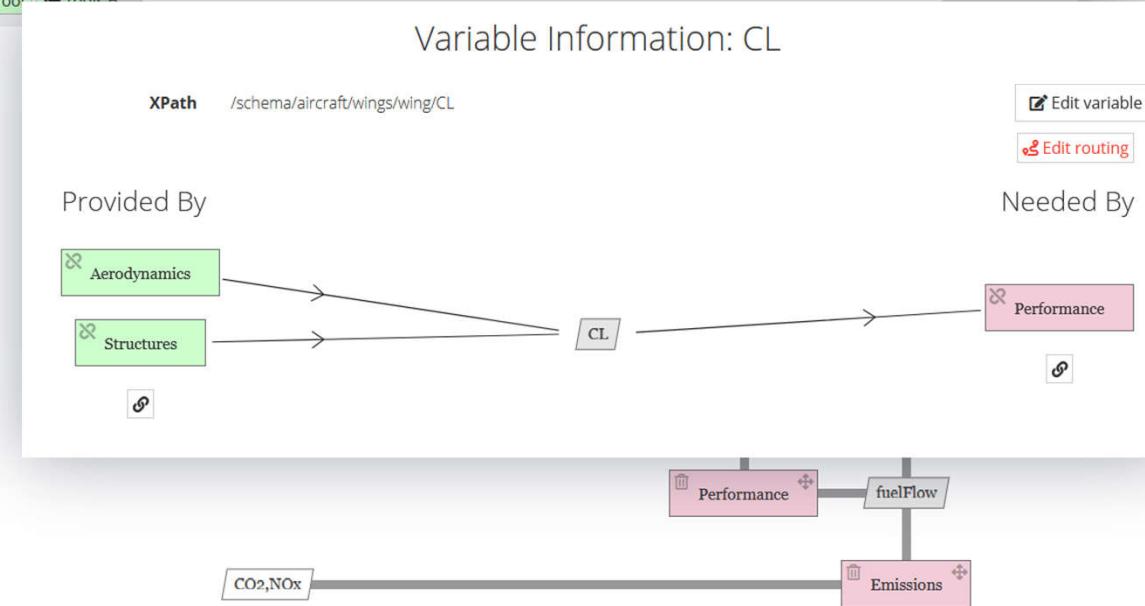
Simple Emissions Initial workflow

Coupling Variables Structures to Performance

Opt DoE Conv Tool Tools B Search: xpath



Press **CRTL-Z** (or click the *Undo* button) to undo this.



Alternatively, you can enter the *Variable Routing* view to resolve collisions. For this, click this *Edit routing* button.



MDAx: MDO Workflow Design x +

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Simple Emissions
Initial workflow

Opt DoE Conv f(m) Tools

/schema/aircraft/wings/wing/CL

Connect functions providing (left) to functions needing (right) this variable:

- Click on a providing, then on a needing function to create a connection
- Click on an arrow to remove the connection

Connection rules:

- Functions are ordered by process order
- Outputs may not be provided to functions after another connection
- Loop boundaries may not cross
- Self-loops are not allowed
- All needing functions must be connected
- First block may be left unconnected if the same block also outputs

Provided By Needed By

System input

Aerodynamics

Structures

Performance

Feedback Feedforward

Cancel Apply

MDAx v0.5.2

The screenshot shows a workflow diagram titled 'Simple Emissions' with the sub-section 'Initial workflow'. On the left, under 'Provided By', there are three boxes: 'System input' (white), 'Aerodynamics' (light green), and 'Structures' (light green). On the right, under 'Needed By', there is one box: 'Performance' (pink). Two red arrows point from the 'Aerodynamics' box to the 'Performance' box, indicating a connection being established or highlighted. The interface includes a top navigation bar with various icons and links, and a sidebar with tool buttons. A status bar at the bottom right indicates 'MDAx v0.5.2'.

Here, click on the source and sink of the connection.

MDAx: MDO Workflow Design x +

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Simple Emissions

Initial workflow

Provided By Needed By

System input → Aerodynamics → Structures → Performance

Feedback Feedforward

Connection rules:

- Functions are ordered by process order
- Outputs may not be provided to functions after another connection
- Loop boundaries may not cross
- Self-loops are not allowed
- All needing functions must be connected
- First block may be left unconnected if the same block also outputs

Connect functions providing (left) to functions needing (right) this variable:

- Click on a providing, then on a needing function to create a connection
- Click on an arrow to remove the connection

/schema/aircraft/wings/wing/CL

MDAx v0.5.2

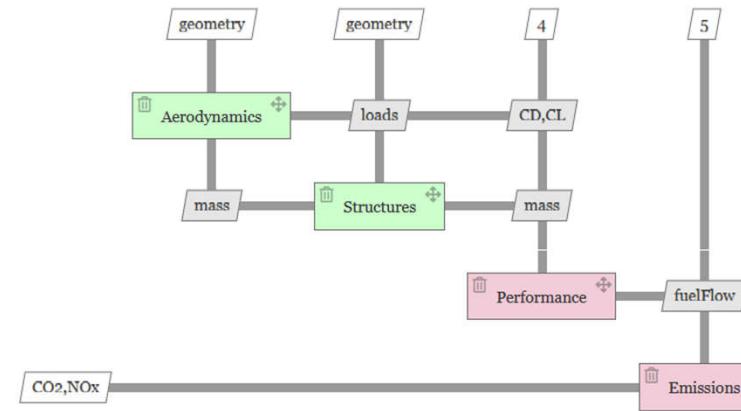
Opt DoE Conv f(m) Tools

Cancel Apply

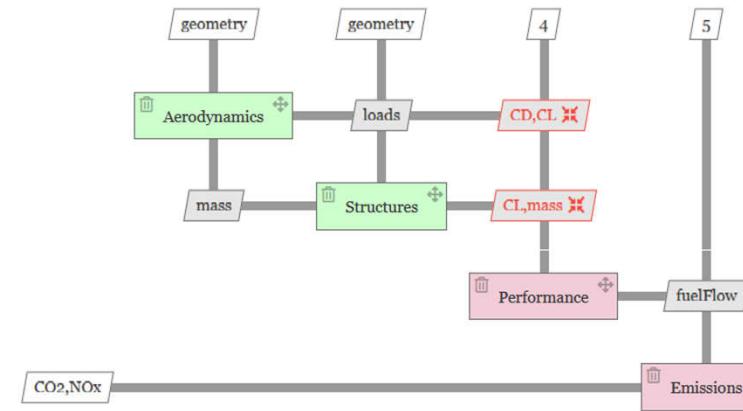
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The screenshot shows the MDAx interface for creating a workflow. On the left, there's a sidebar with tabs like Opt, DoE, Conv, f(m), and Tools. The main area has two columns: 'Provided By' and 'Needed By'. In 'Provided By', there's a box labeled 'o: System input'. In 'Needed By', there's a box labeled 'Performance'. Between them are boxes for 'Aerodynamics' and 'Structures'. A connection arrow points from 'Aerodynamics' to 'Performance'. Another arrow points from 'Structures' to 'Performance'. Vertical double-headed arrows on either side of the flow are labeled 'Feedback' and 'Feedforward'. At the bottom right, there are 'Cancel' and 'Apply' buttons. The top status bar shows the URL https://h2912996.stratoserver.net/app/ and the version 90% MDAx v0.5.2.

This creates a connection for that variable between the selected tools. MDAx disallows connections that introduce further ambiguities. Play around with it to develop a feeling.



Return to the canvas view and find that the collision has been resolved. Press **CTRL-Z** again to return to the earlier state with the collision in place.



An alternative way to resolve collisions is to use the automatic collision resolution algorithms. Click the *Variable Routing Settings* button...

MDAx: MDO Workflow Design

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Simple Emissions

Initial workflow

Variable Routing Settings

Automated variable routing methods solve **collisions**: two or more functions writing to the same variable.

- No automated variable routing
- Latest variable

Each function receives the *latest available* version of the variable. The last globally available version is finalized back once to all tools.
- Closest variable

Each function receives the *closest available* version of the variable.
- Latest-Closest variable

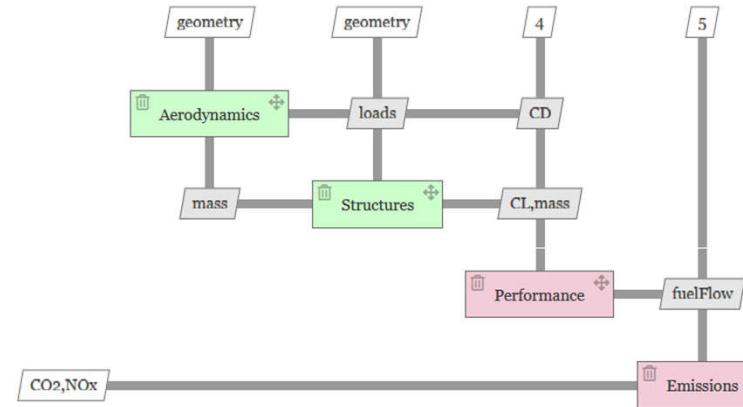
Each function receives the closest available version of the variable, while taking the *latest available* for sequential outputting functions.

Example Result

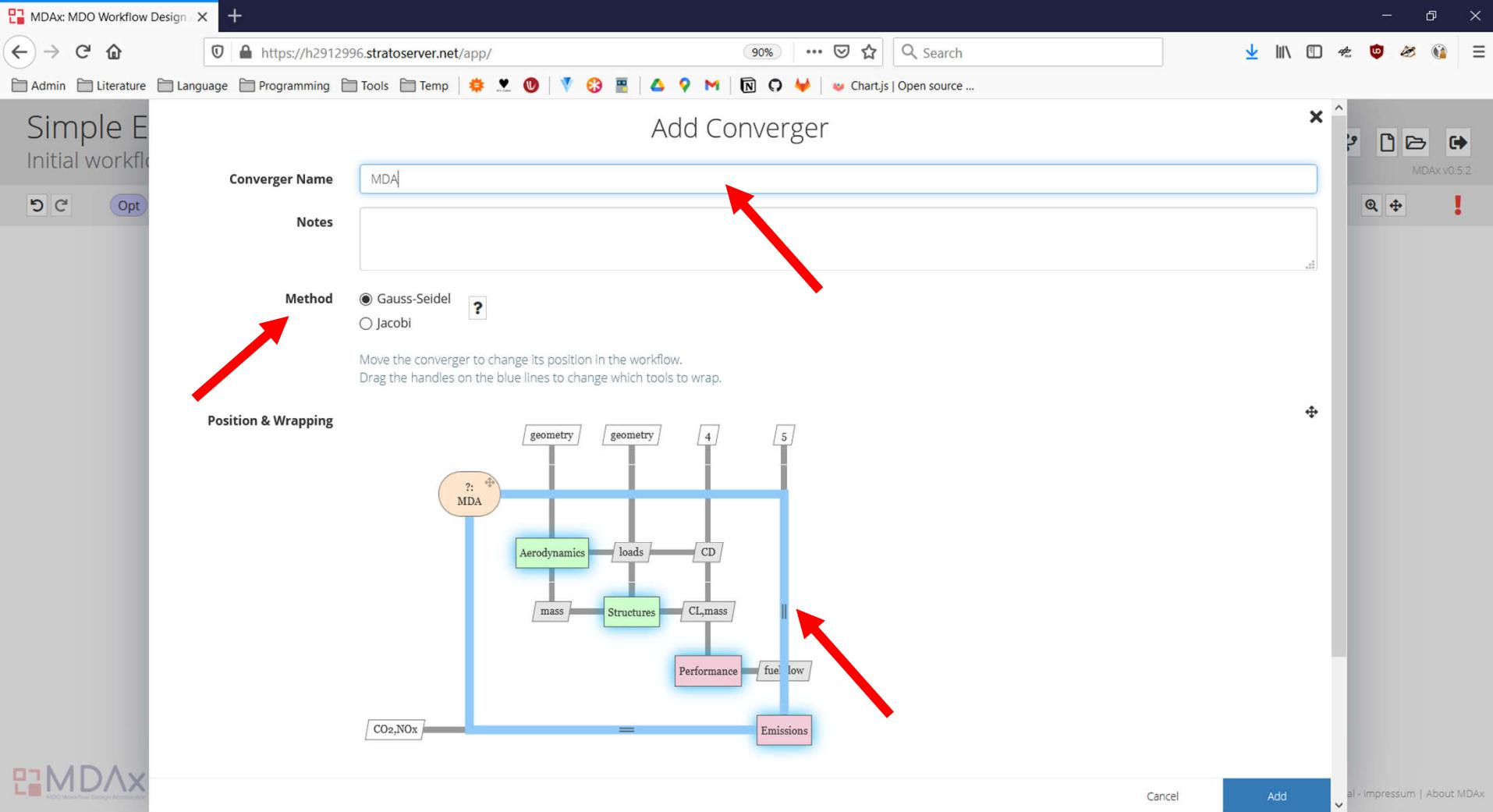
Cancel **Apply**

CO2,NOx Emissions

...and select one of the possible algorithms to resolve collisions. Each algorithm works slightly different, possibly resulting in different workflow connections. The selected algorithm is applied to all outstanding collisions. Click **Apply**.



Note that all collisions are now resolved, and MDAx does not complain. However, it still indicates the existence of feedback connections. To resolve feedback, we need to use **Converger** nodes. Click the **Converger** button.



Set the converger name and method. Drag the blue border lines to set the convergence scope.

MDAx: MDO Workflow Design

Add Converger

Converger Name: MDA

Notes:

Method: Gauss-Seidel Jacobi

Move the converger to change its position in the workflow.
Drag the handles on the blue lines to change which tools to wrap.

Position & Wrapping:

```

graph TD
    geometry1[geometry] --> Aerodynamics[Aerodynamics]
    geometry2[geometry] --> Aerodynamics
    Aerodynamics --> CD[CD]
    Aerodynamics --> Structures[Structures]
    Structures --> CLmass[CL, mass]
    CLmass --> Performance[Performance]
    Performance --> fuelFlow[fuelFlow]
    fuelFlow --> Emissions[Emissions]
    Emissions --> CO2Nox[CO2, NOx]
    CO2Nox --> Emissions

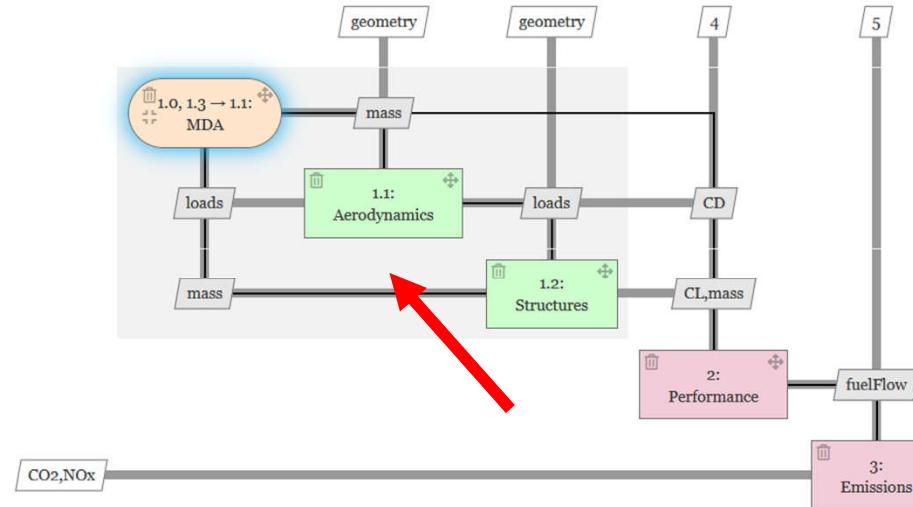
    %% MDA Converger
    MDA((?: MDA)) --- Aerodynamics
    MDA --- Structures
    Aerodynamics --- CD
    Structures --- CLmass
    CLmass --- Performance
    Performance --- fuelFlow
    fuelFlow --- Emissions
    Emissions --- CO2Nox
    CO2Nox --- Emissions
  
```

A red arrow points to the 'lrb' handle of the 'Aerodynamics' tool, indicating where to click to drag the converger.

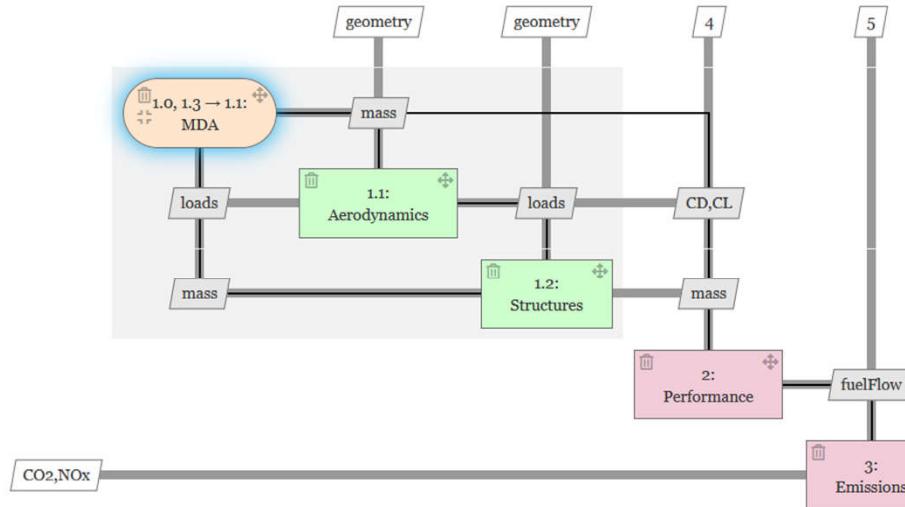
Cancel Add

Since feedback only exists between two tools, we can wrap only those with the converger.

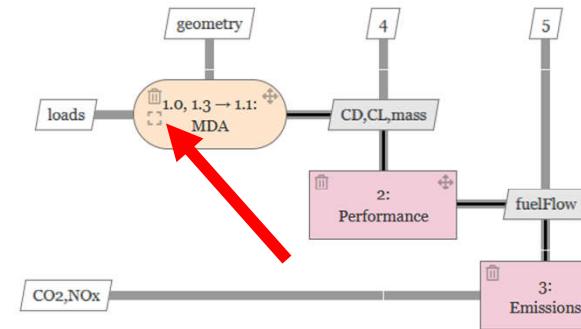
You can optionally add convergence check variables. These variables will be used to check convergence. If none are set, all exchanged variables will be checked for convergence. Click *Add*.



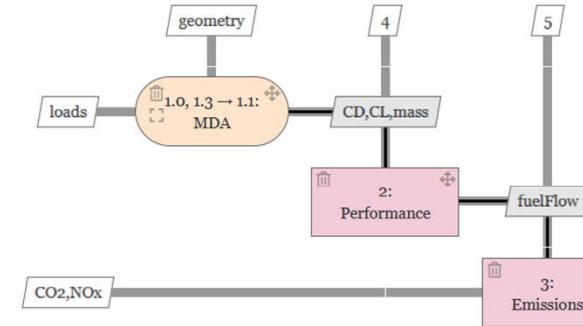
The feedback connections among the wrapped tools are now rerouted through the converger.



MDAx also now indicates that there are no issues and the workflow is executable.



Driver nodes such as a converger can be collapsed for a better overview.



Besides tools, MDAx can also integrate mathematical functions. Click the *Add Math Function* button.

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Simple E... Initial workflow

Add Mathematical Function

Math Block Name: Objective

Notes:

1. Select variables to use as equation parameters, optionally giving them an alias
2. Select the output parent: all expression outputs will be children of this node
3. Enter the equations: use Python syntax, and use the previously entered aliases as variables

Equation Parameters

	Variable	Alias	Actions
		Alias	

Equation output will be written to variables in the *output parent*. It is possible to specify nested child variables using a / delimiter: "child/var" writes the value to var in child, which is located in the *output parent*.

Output Parent Variable required

Equations required

Child Variable Path	Expression (Python)	Actions
Child variable name	= Expression (Python syntax, use available parameter aliases as variables)	

Cancel Add

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Here, define the function name and select the equation parameters (if used).

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Simple E Initial workflow

Add Mathematical Function

Math Block Name: Objective

Notes:

1. Select variables to use as equation parameters, optionally giving them an alias
2. Select the output parent: all expression outputs will be children of this node
3. Enter the equations: use Python syntax, and use the previously entered aliases as variables

Equation Parameters	Variable	Alias	Actions
	CO2	CO2	
	NOx	NOx	
<input checked="" type="checkbox"/>	Alias		

Equation output will be written to variables in the *output parent*.
It is possible to specify nested child variables using a / delimiter: "child/var" writes the value to var in child, which is located in the *output parent*.

Output Parent Variable required

Equations required

Child Variable Path	Expression (Python)	Actions
Child variable name	= Expression (Python syntax, use available parameter aliases as variables)	

Cancel Add

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You can change parameter aliases by pressing the *Edit* button.

Define the output parent..

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Simple E Initial workflow

Math Block Name

Notes

Equation Parameters

Select Output Node

schema

- aircraft
- mission
 - profile
 - emissions
 - CO2
 - NOx

Actions

Cancel Select

Equation output will be written to variables in the *output parent*. It is possible to specify nested child variables using a / delimiter: "child/var" writes the value to var in child, which is located in the *output parent*.

Output Parent Variable required

Child Variable Path Expression (Python) Actions

Child variable name = Expression (Python syntax, use available parameter aliases as variables)

Cancel Add

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...by selecting a branch (non-leaf) variable. Click *Select*.

Now define the variable name (output variable), the expression, and click the *plus* button.



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Initial workflow

Opt

Math Block Name Objective

Notes

1. Select variables to use as equation parameters, optionally giving them an alias
2. Select the output parent: all expression outputs will be children of this node
3. Enter the equations: use Python syntax, and use the previously entered aliases as variables

Equation Parameters	Variable	Alias	Actions
	CO2	CO2	[edit] [delete]
	NOx	NOx	[edit] [delete]
	<input checked="" type="checkbox"/>	Alias	[+]

Equation output will be written to variables in the *output parent*.
It is possible to specify nested child variables using a / delimiter: "child/var" writes the value to var in child, which is located in the *output parent*.

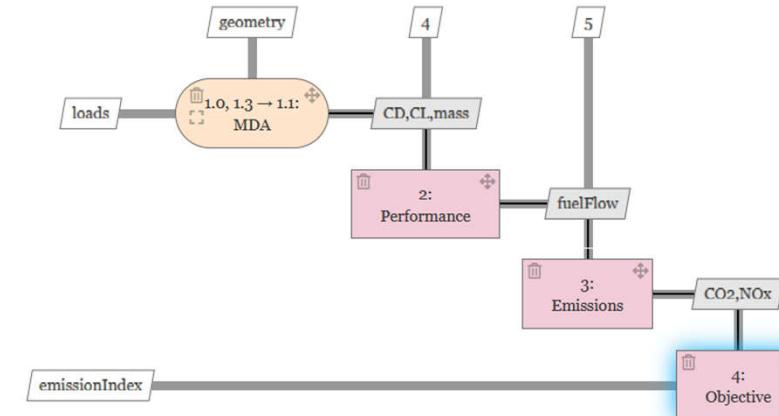
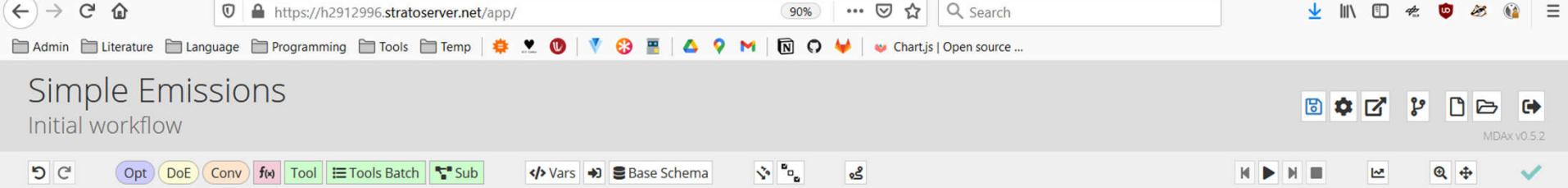
Output Parent Variable /schema/mission/emissions

Equations	Child Variable Path	Expression (Python)	Actions
	emissionIndex	= 2*CO2 + 3*NOx	[edit] [delete]
	<input type="text" value="Child variable name"/>	<input type="text" value="Expression (Python syntax, use available parameter aliases as variables)"/>	[+]

Cancel Add

MDAx MDO Workflow Design Administration

Finally click *Add*.



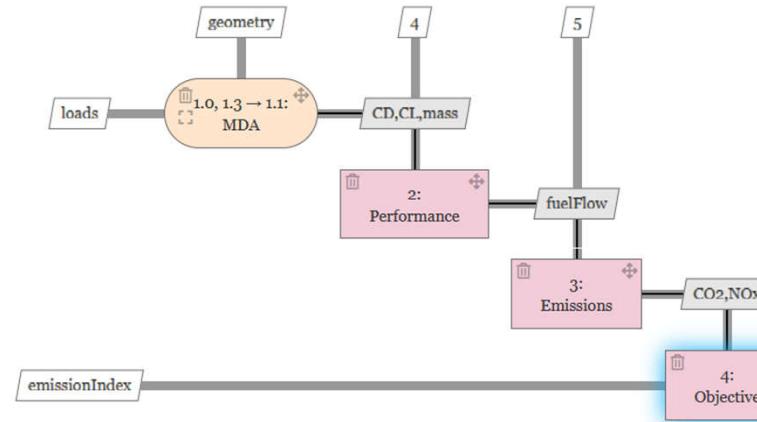
The mathematical function now appears on the canvas, with appropriate input and output connections.

Simple Emissions
Initial workflow

MDAx v0.5.2

Opt DoE Conv Tool Tools Batch Sub Vars Base Schema

MDAx v0.5.2



We can use this workflow to run an optimization. To do this, we can add an Optimizer node using the *Optimizer* button.

Similar to the converger, we can drag the blue line to define the tools that are wrapped by the optimizer.

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Initial workflow

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emissionIndex

2: Performance

fullFlow

3: Emissions

CO₂

4: Objective

Only variables that are *exclusively* input to the wrapped functions are available for selection as design variables. If the desired design variables are not available for selection, carefully check the I/O of the wrapped functions to make sure the design variables are not written to.

Design variables are the parameters varied by the optimizer to optimize the design.

Design Variables required	Variable	Lower Bound	Nominal Value	Upper Bound	Actions
	<input checked="" type="checkbox"/> Lower	<input type="text"/>	<input type="text"/> Nom	<input type="text"/> Upper	<input type="button" value="+"/>

Objectives are the parameters that should be minimized in order to produce a "better" design.

Objectives required	Variable	Actions
	<input checked="" type="checkbox"/> <input type="button" value="+"/>	

Constraints limit the feasible design space in which the optimizer can search for an optimal design.

Constraints	Variable	Type	Reference Value	Actions
	<input checked="" type="checkbox"/>	<input type="text"/> <=	<input type="text"/> 0	<input type="button" value="+"/>

Cancel Add

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Select the design variables and objectives and add them using the *plus* buttons. You can optionally set the bounds and nominal values for each design variable.

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Design Variables

Design Variables	Variable	Lower Bound	Nominal Value	Upper Bound	Actions
	climbRate				
	designSpeed				
	geometry				

Objectives

Objectives	Variable	Actions
	emissionIndex	

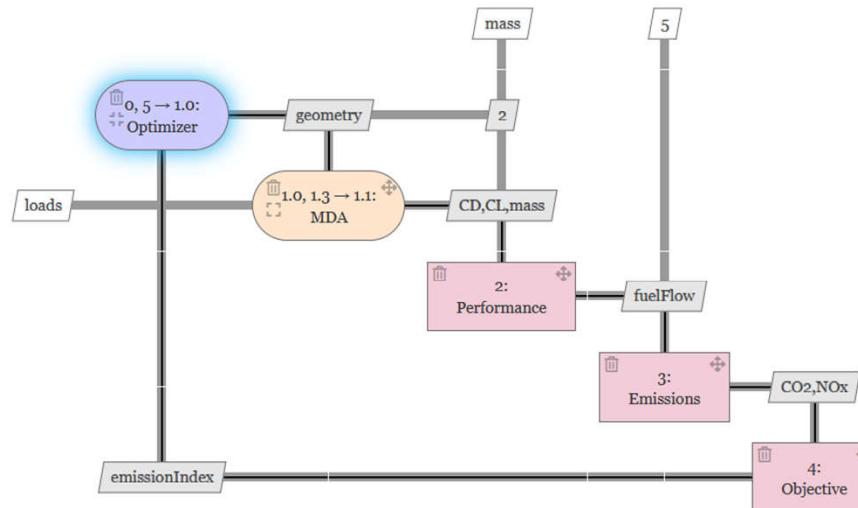
Constraints

Constraints	Variable	Type	Reference Value	Actions
	<input checked="" type="checkbox"/>	<=	0	

Cancel Add



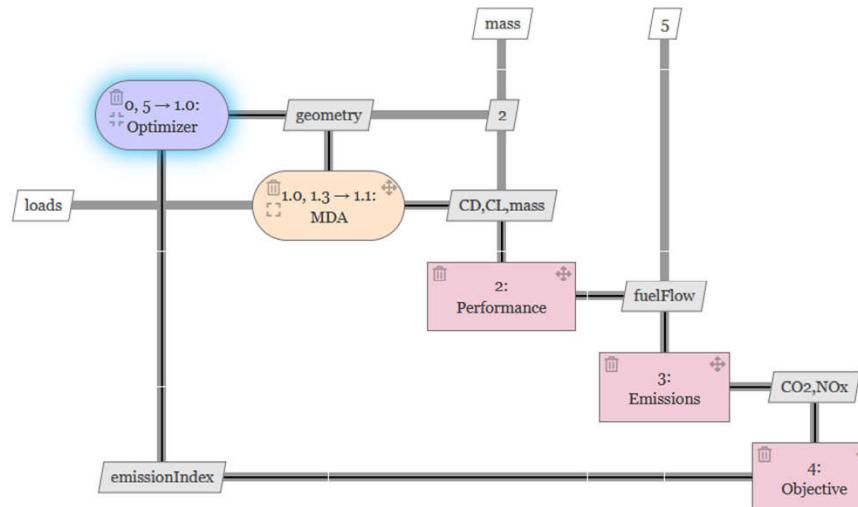
You can optionally select and add design constraints. Once finished, click Add.



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The optimizer is now present on the canvas. To save this workflow model, click the **Save** button and download the model file.





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To export this workflow into other formats, click the *Export* button...



The screenshot shows the MDAx: MDO Workflow Design application interface. The main title is "Export: Simple Emissions" under "Initial workflow". Below this are several export options:

- XDSM (PDF) icon: A document with a PDF icon.
- XDSM (SVG) icon: A document with a camera icon.
- Interactive XDSM (HTML) icon: A document with code brackets icon.
- MDAx Project icon: The MDAx logo with the text "MDAx MDO Workflow Design Accelerator".
- RCE (local) icon: The RCE logo.
- RCE (CPACS) icon: The RCE logo with a "CPACS" icon.
- RCE (Brics) icon: The RCE logo.
- CMDOWS icon: The CMDOWS logo.
- Tool I/O icon: A diagram showing a "Tool" box with an "I" input and an "O" output.

At the bottom, there is a large "Workflow Input" section with a large arrow pointing right.

...and select the format you want to export it to. For visualization, use the *PDF*, *SVG* or *interactive HTML* export. For execution, use the *RCE* or *CMDOWS* exports.



For more MDAx examples, check out the following repos:

- <https://github.com/andreas-pr-dlr/mdax-sellar>
- <https://github.com/andreas-pr-dlr/mdax-emissions>
- <https://github.com/andreas-pr-dlr/mdax-hep>
- <https://github.com/andreas-pr-dlr/mdax-ssbj>

Access the app via [https://mdax.agile4.eu/app/.](https://mdax.agile4.eu/app/)

